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Effects of Neuromuscular Fatigue Resulting from Repeat Sprint Exercise Among Trained Cyclists on Measures of Strength and Power Performance

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Effects of Neuromuscular Fatigue Resulting from Repeat Sprint Exercise Among Trained Cyclists on Measures of Strength and Power Performance

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by

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ABSTRACT

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The purpose of this dissertation is to better understand the role of repeated-sprint ability (RSA) and resulting fatigue in cyclists; how it relates to measures of aerobic power and strength and power performance indices- due to the nature of cycling competitions and the necessity of RSA for success.

The first part of this dissertation attempted to elucidate the relationship between RSA and aerobic power and strength/ power measures in competitive cyclists. The purpose was to potentially illustrate the importance of the inclusion of strength and power training in the training regimen of cyclists. The findings showed several statistically significant relationships between variables of RSA and aerobic power or the isometric squat test.

The second part of the dissertation examined the effects of fatigue induced from the acute bout of repeat sprint exercise on strength and power measures in three different recovery periods. It is commonplace for cyclists to have several heats in one day of racing. Examining the effects of fatigue on strength measures such as peak force and rate of force development could begin to delineate how an individual experiences fatigue based on their own characteristics, enabling them to design a training program to address these

strengths/ weaknesses to optimize performance and decrease fatigue. The results from a repeated measures analysis of variance found no statistically significant effect on PF or RFD. Additional comparisons showed moderate effects of fatigue on RFD throughout the three post-RSE trials. There was also a moderate correlation between the RSE fatigue % decrement score and the isometric RFD fatigue % decrement score.

What we may conclude from this dissertation is that fatigue has various causes and can vary with an individuals' unique physiology and how they respond to performance variables on any specific day can vary. Development of increased strength and subsequent power, or "explosive strength", may have advantages in competitive cycling. Coupling proper strength and power training with an aerobic training regimen, may greatly benefit the athlete by increasing their peak power output, economy of movement, delaying fatigue, improving anaerobic capacity, and overall enhancing their maximal speed.

DEDICATION

This work is dedicated to my family for all of their love and support throughout this long and tedious process.

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CHAPTER 1

Introduction

To introduce this dissertation, a general understanding that there has been little research specifically investigating the role of repeat sprint ability in competitive road cyclists, should be considered. The majority of the recent research into this topic has investigated its role and importance in traditional team-based field/court sports. Interestingly, the physiological demands of competitive road cycling may be one of the most challenging of all sports- by combining a variety of durations, intensities, and frequencies in one event (Jeukendrup et al., 2000). With this understanding, anaerobic power and neuromuscular characteristics are involved in long duration endurance performance, especially when athletes are matched for aerobic power (Bulbulian et al., 1986; Houmard et al., 1991; Paavolainen et al., 1999). In other words, at the elite level of endurance sport- most competitors are largely equally matched in terms of aerobic power capabilities, the crucial difference exists for those that have an equally impressive ability to sprint, and repeat that sprint throughout the race. Therefore, the resultant fatigue experienced from repeated sprints experienced during a race may be the deciding factor of where and when an individual athlete may win or lose that event. As such, repeat sprint ability can be viewed as a determining factor of success in competitive road cycling races.

There is still no clear explanation of the mechanisms that limit repeat sprint performance, however we have garnered understanding that repeat sprint ability deteriorates substantially with fatigue development (Glaister 2005; Girard et al., 2011), during cycling specific RSE this culminates as a reduction in maximal power output. Delineating an individuals' unique aerobic power and explosive strength capabilities, and subsequent effect of fatigue on them is a necessary step in order to better design interventions that would impact the participants' unique physiology, thereby positively impacting future training and performances through optimal program design interventions to target delaying onset of fatigue.

The purposes of this dissertation were to attempt to better understand the role of repeated-sprint ability (RSA) and resulting fatigue in cyclists; how it relates to measures of aerobic power and measures of strength and power- due to the nature of cycling competitions and necessity of RSA for success. Specifically study 1 was an attempt to elucidate the relationship of aerobic power and strength measures (kinetic variables from an isometric squat exercise) on repeat sprint ability (RSA) in competitive cyclists, potentially illustrating the importance of the inclusion of strength training in the training regimen of cyclists. The purpose of study 2 was to examine the effects of fatigue from an acute bout of repeat sprint exercise on strength measures and the effects of three different recovery periods on these measures. Examining the effects of fatigue on explosive strength measures could begin to delineate how an individual experiences fatigue based on each of his/her individual characteristics and enable them to design a training program to address these strengths/ weaknesses to further optimize performance and decrease fatigue onset.

CHAPTER 2

REVIEW OF LITERATURE

Characteristics of Competitive Cycling

The sport of road cycling is an endurance activity (Faria et al., 2005), and consequently has synonymously been associated with low intensity exercise endurance (LIEE). What individuals may not sufficiently realize is that this endurance sport discipline may be one of the most challenging of all sports by combining a variety of durations, intensities, and frequencies in one event (Bangsbo 2000; Jeukendrup et al., 2000).

Competitive cycling events are inherently stochastic in nature (Allen & Coggan 2010), requiring repeated accelerations throughout that rely on both aerobic and anaerobic power; which require a successful cycling athlete to possess an ability to produce repeated high power bouts of a short duration while continuing high overall power for long duration (Faria et al., 2005). To deliver an optimal performance, cycling speed will have to increase to a point where demand for power matches the power supply from all energy sources available (Olds et al., 1993). The necessity to cycle at a faster velocity than one's competitors in any competitive road cycling event will be dependent on a multitude of complex interactions based on the athlete's physiological state (e.g. an athlete's aerobic power [VO_2max], their lactate threshold [LT], economy of movement and gross mechanical efficiency on the bike), environment in which the athlete must perform (e.g.; environment temperature, humidity, wind velocity and direction, altitude, gradient of course, terrain type) and mechanical variables (ie; type of bicycle used, aerodynamics of machine, tire application for terrain, components, and gearing) (Jeukendrup et al., 2000).

In addition to low intensity exercise endurance (LIEE), the variety of factors (physiological, environmental, and mechanical variables aforementioned) impacting performance require moderate intensity exercise endurance (MIEE) and high intensity exercise endurance (HIEE) for success. With this understanding, anaerobic power and neuromuscular characteristics are and should be factored into long duration endurance performance, especially when athletes are matched for aerobic power (Bulbulian et al., 1986; Houmard et al., 1991; Paavolainen et al., 1999).

Resultant and excess fatigue experienced by a cycling athlete from repeated sprint bouts experienced during a race may be the deciding factor of where and when the athlete may win or lose that event. As such, repeat sprint ability can be viewed as a determining factor of success in competitive cycling races. In support of this notion, with the analysis of thousands of power meter files from competitive cycling (road, track, mountain) events, Allen and Coggan noted that the most successful cyclists were those that pedaled least, but when they did pedal they pedaled with the most force (Allen & Coggan 2010).

Repeat Sprint Ability

Repeat sprint ability (RSA) has been defined as the ability to produce, recover from sprinting effort, and then reproduce subsequent high-intensity sprint efforts (Fitzsimons et al., 1993; Turner & Bishop 2018). RSA requires both high maximal sprinting power and the ability to maintain a high maximal average power during subsequent sprints (Turner & Bishop 2018). This sport-specific skillset has been discussed in literature with many applications to many field and racquet-based team sports such as soccer, field hockey, and rugby (Girard et al., 2011) but there has been little research dealing specifically with the importance of RSA in competitive cycling events. Traditionally, athletes engaged in RSA type events have been characterized as having the ability to produce maximal efforts combined with brief recovery periods, which may include complete rest or low to moderate activity, all performed over an extended time frame of one to four hours (Fitzsimons et al., 1993; Girard et al., 2011; Glaister 2005). For the purposes of this review, repeat sprint exercise (RSE) is the act of short-duration ($\leq$ 10 seconds) sprints with brief recovery periods (usually $\leq$ 60 seconds) (Bishop et al., 2004).

The impact of training state; an individual having either superior aerobic power or strength characteristics, on repeat-sprint ability and subsequent success in a cycling race, can be further delineated with implications on individual characteristics needed to be improved by the athlete.

With an increase of research on repeat sprint ability since the early 2000's there is still no clear explanation of the mechanisms that limit repeat sprint performance. However, we have garnered understanding that repeat sprint ability deteriorates substantially with fatigue development (Girard et al., 2011; Glaister 2005), and during cycling specific repeat sprint exercise (RSE) this culminates as a reduction in maximal power output. Accumulative fatigue is heavily dictated by the first sprint, and it has been shown that aerobically trained athletes have lower peak power output but maintain similar average power outputs, or have greater fatigue resistance than their more anaerobically-trained counterparts who have much higher peak power outputs but experience much more fatigue development (Bishop 2012; Girard et al., 2011).

Aerobic Power

Aerobic power, measured indirectly in an individual by measuring the maximal rate of oxygen consumption (VO_{2max}) has been deemed the best method to determine an individual's ability to utilize oxygen from inspired air, load the oxygen into the blood through the cardiorespiratory system, and transport it to working muscle tissue to continue mechanical work (Brooks et al., 2005; Sleivert 2002). The oxygen volume being consumed per minute (VO_2) is dependent on an organisms cardiac output (central factor) and arteriovenous oxygen difference (a-VO_{2}) (peripheral factor) (Stone et al., 2007). During exercise bouts that require less than maximal output, VO_2 will increase until oxygen demands of the working tissue can be met by supplied oxygen- signifying a steady state (Astrand & Rodahl 1970). Despite an equal balance of supply and demand, the initial increase of work above a resting state will have been enabled by some form of metabolic energy. This energy cost is afforded by anaerobic pathways and is termed the oxygen deficit (Astrand & Rodahl 1970; Brooks et al., 2005). When exercise is stopped or ceases to continue, VO_2 will remain elevated above resting levels dependent on intensity and duration of exercise. This elevated level of VO_2 has been called many different terms; O_2 debt, excess post-exercise oxygen consumption (EPOC), and recovery oxygen (Brooks et al., 2005; Hill et al., 1924; Stone et al., 2007).

Strength/ Power

Strength is simply defined as an ability to produce external force by contraction of a muscle or group of muscles under a specific set of conditions (Stone et al., 2007). Applying maximal force quicker than an opponent is where most competitors will gain an advantage. This association of force and time, referred to as rate of force development (RFD), is related to Newton's second law, where force equals mass times acceleration (Stone et al., 2016). Power is the product of force and velocity or a work rate; generally power output stratifies competitors (Stone et al., 2007, Stone et al., 2004). Rate of force development (RFD) and resultant power are important characteristics of strength (force) production (Stone et al., 2016). The ability to generate force and apply it rapidly may be a key component in determining success in athletic pursuits, in this case, competitive cycling races.

The coupling of the capability to produce immense external force, or strength, in a very fast manner is what will produce a favorable RFD. This high RFD has shown a greater relationship to athletic success (Suchomel et al., 2016).

Power, a product of force and velocity or work / time, comes from immediate and non-oxidative energy sources (Brooks et al., 2005). In recent research, it is widely evidenced that the ability to produce instantaneous force is related to success in sport (Stone et al., 2002; Suchomel et al., 2016).

Fatigue

In terms of exercise and work, fatigue has been defined as the inability to maintain or repeat a given output or intensity level (Brooks et al., 2005; Stone et al., 2007). This development of fatigue can be caused by a variety of variables, from neural to muscular factors and the complexity of the causes are seemingly more individualistic interchanges based on the individual being tested (Girard et al., 2011; Glaister 2005). The cause of performance decrements underlying the difference in peak power and subsequent trials is currently, for the most part, unknown. Fatigue has been defined as a reversible decrease in maximal power output, despite the ability to continue the specified task (Bishop 2012). This exercise-induced fatigue may be caused by a variety of reasons that range from first sprint power exhibited, nature of the task, and neural to peripheral factors (Bishop 2012).

The importance of the first, or initial, sprint performance has been correlated to power output in subsequent sprints (Bishop et al., 2003; Bishop 2012; Mendez-Villanueva et al., 2008). This may be related to an increased dependence on anaerobic metabolism to supply the muscular function needed for a maximal contraction initially;

producing larger disruptions in muscle metabolites, pointing towards the force-dependent metabolic pathways that support force production regardless of force or power output produced in subsequent trials (Gaitanos et al. 1993; Mendez-Villanueva et al., 2008). The specific task being performed by an individual and their respective experience with a specific task may also have a role in fatigue experienced, as do the intensity, duration and type of contraction (Bishop 2012). Recent studies have reported that trial distribution, trial length, recovery period, recovery type (active or passive), type of resistance, and modality of delivery all have an impact on the fatigue decrement (Bishop 2012; Girard et al., 2011; Signorile et al., 1993).

Consideration of neural factors commonly leads to examination of surface electromyography (EMG) and whether the ability to activate working muscles is still present as a result of fatigue. Several studies have reported decreases in mechanical scores as well as amplitude of EMG signals, this has been evident at fatigue levels greater than 10% (Billaut & Bishop 2009; Girard et al., 2011; Mendez-Villanueva et al., 2007; Mendez-Villanueva et al., 2008; Racinais et al., 2007). The use of EMG was not implemented for the current study and is therefore beyond the scope of this paper.

Peripheral factors that relate to overall fatigability of an individual have associations with muscle excitability, energy supply, and accumulation of metabolites (Bishop 2012; Girard et al., 2011). Specifically discussing muscle excitability, with mechanical work at the skeletal muscle level, ionic alterations give way to decreases in sodium (Na^+)/ potassium (K^+)- adenosine triphosphate (ATP) activity (Brooks et al., 2005). Under intense working conditions, the Na^+/ K^+ pump, which regulates muscular contraction and relaxation, cannot steadily balance the K^+ efflux out of the cells, thereby inducing an excess of muscle extra-cellular K^+ concentration (Girard et al., 2011; Juel et al., 2000). This extra-cellular K^+ ultimately impairs membrane excitability and depresses force development, by slowing inactivation of Na^+ channels and thereby reducing action potential amplitude which leads to a slowing of impulse conduction (Fuglevand et al. 1993; Girard et al., 2011; Ruff et al., 1988).

The most immediate energy supply for anaerobic pathways is produced via intramuscular phosphocreatine (PCr). Total stores in the human body are approximately 80 mmol·kg dm^{-1}, with maximal rates of breakdown that can reach 9 mmol·kg dm^{-1} (Bishop 2012; Girard et al., 2011). With particular interest in the case of RSE, stored PCr after a 6 second maximal sprint can be diminished to 35-55% of resting values with complete recovery sometimes requiring in excess of 5 minutes (Gaitanoset al., 1993; Girard et al. 2011; Tomlin & Wenger 2001). With the replenishment and complete resynthesis, it is likely that ATP/ PCr stores will only be somewhat restored before the next interval of an RSE test protocol. This inadequate replenishment of ATP/ PCr may severely limit subsequent maximal power output by an individual during repeated trials. The work of Girard, Mendez Villanueva, and Bishop suggests that more careful distribution of power output may attribute to superior PCr resynthesis during recovery periods (Girard et al., 2011).

The next most immediate energy pathway is that of anaerobic glycolysis. Anaerobic glycolysis can be responsible for as much as 40% of total energy during a 6 second maximal sprint bout with diminishing contribution during an RSE protocol, which can be as high as an 8-fold decrease over 10 trials (Gaitanos et al., 1993; Girard et al., 2011). What remains unclear with regards to anaerobic glycolysis is that if improving the maximal rates of glycolytic contributions would lead to superior performances in a RSE endeavor. An enhancement of glycolytic ATP contribution could enhance power output subsequent to the initial sprint which may impact fatigue resistance and could enhance power output during subsequent trials (Girard et al., 2011).

Finally, oxidative metabolism during any RSE protocol, though quite a small contributor initially (less than 10%), can increase contribution to as much as 40% of total energy supply during the last sprints of an RSE testing protocol (Bishop 2012; Girard et al., 2011). Therefore it is not surprising that RSE performance may be enhanced by the ability to use aerobic power, this could increase fatigue resistance, especially in the latter trials of the RSE testing protocol. It is also possible that enhanced aerobic power may increase the recovery rate of energy substrates between bouts, thus allowing the maintenance of power output (Glaister et al., 2005). Studies have reported significant correlations between VO_2max and fatigue decrements, presenting better fatigue resistance in those individuals with larger aerobic power capabilities (Edge et al., 2006; Glaister 2005). To confound this issue, other researchers have reported non-significant correlations between these performance measures (Aziz et al., 2007; Castagna et al., 2007; Dardouri et al., 2014). But the differences may be due to variations in sample size and protocols used to determine RSA performance.

The accumulation of metabolites (hydrogen ions) in muscle and blood during fatigue inducing exercise, such as the RSE protocol, can be supported by research findings and may be associated with adverse effects on performance (Bishop et al., 2003, Bishop & Edge 2006; Spencer et al., 2008). These accumulated metabolites may have a direct effect on ATP delivery by changing blood pH, but this has been greatly disputed in the literature (Girard et al., 2011).

Assessing fatigue, or more specifically, calculating a fatigue decrement is a necessary step in order scale the level of performance loss experienced. To accurately measure performance drop-off during a bout of repeat sprint work, several authors have investigated the impact of calculation methods on the reliability of fatigue scores during repeated sprints. Oliver reported improved reliability when the performance reduction during a repeated sprint test was reported as a percentage decrement score, as opposed to a fatigue index (Glaister 2008; McGawley & Bishop 2006; Oliver 2009). This method is still inclusive of variability with CVs ranging between 11 and 50% (Bishop & Spencer 2004; Glaister et al., 2004, McGawley & Bishop 2006, Oliver 2009; Oliver et al., 2006). Utilizing test data, the percentage decrement can be calculated from the mean sprint time and the fastest sprint time, which have been shown to be reliable, with CVs < 2.7% (ICC) across a number of studies (Oliver et al., 2006; Spencer et al., 2006).

Conclusion

With the wide array of variables effecting performance, especially competitive cycling, be it environmental or physiological aspects- these variables all have far-reaching effects on one another. Possessing a superior repeat sprint ability (RSA) may be a deciding factor for success in many sports. Research has shown this time and time again, but little is still known about the actual causes of fatigue during RSE. This ranges from central factors to localized peripheral factors, and has been synonymously attributed to such despite inconclusive findings. Fatigue, especially fatigue during RSE is complex, at best. More multi-collaborative research initiatives are needed to continue the exploration into this fascinating phenomenon.

CHAPTER 3

STUDY METHODS

Introduction

To investigate the relationship of fatigue from a repeated sprint cycle exercise on strength and power measure indices, a two part study was carried out. The first part of this study was to evaluate the relationship of aerobic power and strength measures on repeat sprint ability in competitive cyclists. The second part of the study evaluated the effect of fatigue on measures of strength, specifically peak force and rate of force development.

In order to carry out these investigations, the following instrumentations were used:

Instrumentation

Refractometer- (Atago, Tokyo, Japan)

Lange Skinfold Calipers (Beta Technology Inc., Cambridge, MA)

Velotron Cycle Ergometer- (Racermate Inc., Seattle, WA)

TrueOne 2400 Metabolic Cart (Parvo Medics, Sandy, UT)

Custom Built Isometric Rack

Force Plate dual design (RoughDeck HP, Rice Lake, WI)

LabVIEW (version 2015, National Instruments, Austin, TX)

JASP Team (Version 0.10.0, Amsterdam, Netherlands)

Microsoft Excel- (Microsoft Corporation, Redmond, WA)

IBM SPSS Statistics- (Version 25, IBM Corporation, Armonk, NY)

Participants

Targeted Population: Multi-discipline competitive cyclists

Sample Size: n = 10

Table 1.

Descriptive Statistics

Variable	*Mean*	±	*SD*
Age (y)	22.3	±	4.9
Height (m)	1.73	±	0.5
Body Mass (kg)	68.5	±	7.3
Body Fat (%)	11.6	±	7.1
VO_2 ($ml \cdot kg \cdot min^{-1}$)	67.3	±	9.3
VO_2 ($L \cdot min^{-1}$)	4.6	±	0.6

Sampling Method: Convenient (within cycling-specific community of nearby cycling teams and clubs)

All testing sessions took place in the Sport Science Laboratory on the campus of East Tennessee State University in accordance with East Tennessee State Institutional Review Board guidelines. Participants read, signed and acknowledged the processes for all testing described/ detailed in the form of the University approved Informed Consent Document prior to beginning any of the research testing protocols.

Procedures

All study participants completed two testing sessions, with at least 1 week between testing sessions. The first session was composed of the following assessments in order: urine specific gravity hydration assessment, body composition assessment, resting heart rate, standardized cycle ergometer warm-up of 10 minutes including three 6 sec sprint familiarizations (5 minutes at 100-120 watts, (3) 6 seconds sprint with 60 second recovery, 2 minutes at 100-120 watts), 2 minute rest period, maximal VO_2 test, a 10 minute rest period, then an isometric squat position trial/ familiarization. The second session was comprised of the following assessments in order: urine specific gravity hydration assessment, a standardized general warm-up and specific warm-up protocols, isometric squat testing (IST-Pre), a repeat sprint cycle ergometer test (RSE) of (15) x 6 seconds with 30 second passive recovery, isometric squat testing (IST-Post), 10 minute recovery period, isometric squat testing (IST-Post10), 15 minute recovery period, and concluded with isometric squat testing (IST-Post25).

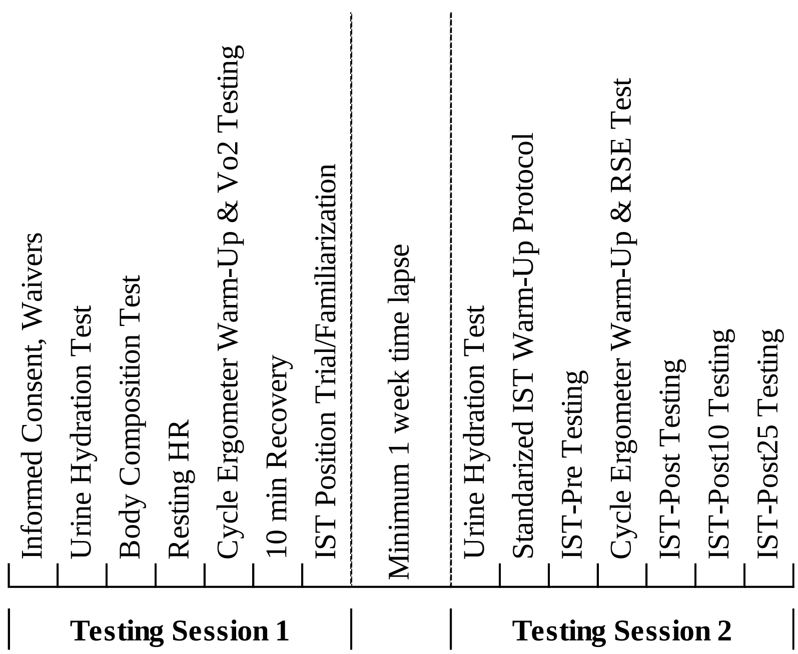

Figure 1. Study Procedure Timeline

Testing Protocols

Hydration Analysis & Body Composition Testing

Study participants completed a urine specific-gravity testing assessment to assess hydration status and ensure adequate hydration levels. Study participants were instructed to provide a “clean-catch” urine sample, requiring the participant to wash hands before obtaining sample, then starting urination in toilet bowl, stopping the urine flow, then collecting a sample of urine in clean collection cup, sealing collection cup with provided cap. All urine samples were tested using a digital refractometer (PAL 10S, Atago USA, Incorporated) to obtain a urine specific gravity value. Participants with a urine specific gravity of < 1.020 were classified as adequately hydrated and were allowed to continue with the testing session. Participants who had a urine specific gravity that is ≥ 1.020, were required to hydrate with water and were retested before continuing with the session. Following the hydration test, anthropometrics were recorded by measuring participant height, body mass, and skinfolds. Height (cm) was measured using a digital stadiometer and body mass (kg) was measured using a digital scale. Two measurements were performed each time for reliability. A seven site skinfold procedure (triceps, subscapular, midaxillary, suprailiac, abdomen, chest and thigh) was measured using Lange skinfold calipers (Beta Technology Inc., Cambridge, MA, USA) following ACSM guidelines by the same investigation team member.

Aerobic Power Testing

Immediately following the urine specific-gravity hydration and body composition tests, study participants remained seated in a chair to determine a resting heart rate (HR). Study participants then mounted the electronically-braked cycle ergometer (Velotron, Racermate Inc., Seattle, WA), which was adjusted to reflect the measurements of each participants own bicycle to ensure more familiarity and comfort of fit during the test. The use of cycling specific shoes and the participants' own pedal system were fitted to the cycle ergometer. Following those steps, participants completed a standardized warm-up protocol, consisting of 5 minutes at 100-120 watts, (3) 6 second maximal sprints with 30 seconds of recovery between each, followed by 2 minutes of easy pedaling at 100 watts on the cycle ergometer before the start of the maximal oxygen uptake (VO_2 max) testing assessment. The standardized warm up is an adaptation of a standardized protocol of Billaut and colleagues and of that recommended by Craig and colleagues (Billaut et al., 2006; Craig et al., 2000). The maximal oxygen uptake testing portion is a ramp incremental test. Resistance loads were standardized based on study participant body mass with starting wattages differing for males and females (see table 1) (Balmer et al., 2000; Winter et al., 2006). Testing concluded when participant could no longer maintain a cadence of 70 revolutions per minute or voluntarily terminated the test because they felt they could not continue.

Table 2.

Ramp Test Reference Values

Weight (kg)	Males		Female	
	Start (w)	Ramp (w· min^{-1})	Start (w)	Ramp (w· min^{-1})
< 45			100 - 120	13
45 - 49			110 - 130	14
50 - 54	140 - 160	17	120 - 140	15
55 - 59	150 - 170	18	130 - 150	16
60 - 64	160 - 180	19	140 - 160	17
65 - 69	170 - 190	20	150 - 170	18
70 - 74	180 - 200	21	160 - 180	19
75 - 79	190 - 210	22		
80+	200 - 220	23		

Inspired and expired gases were assessed using a metabolic cart (TrueOne 2400, Parvo Medics, Sandy, UT) to determine the VO_2 per stage. Calibration measurements were performed prior to each test. A two-point calibration of gases was performed with an exact compound mixture (16.01% Oxygen, 4.01% Carbon Dioxide, BAL% Nitrogen) and room air. A 3-L syringe was used for the flow-meter calibration. After completion of the warm-up period, the participant was fitted with a head harness and corresponding mouthpiece with a two-way valve and hose to collect gases, and nostril clamp. Data was collected continuously for minute ventilation (VE), and respiratory exchange ratio (RER). All values are retrieved in breath-by-breath measures. The gases were analyzed over 15 second averages using the metabolic cart specific analysis software. The metabolic cart data file was exported and analyzed using Microsoft Excel (Microsoft, Redmond, WA) and JASP (Version 0.10.0, Amsterdam, Netherlands) software after completion of the testing session for analysis. Velotron cycle ergometer (Racermate Inc., Seattle, WA) supplied software was used for recording power and cadence data, export of data to a

Comma Separated Values (CSV) file will occur after each participants' completion for further analysis using Microsoft Excel- (Microsoft Corporation, Redmond, WA) and JASP (Version 0.10.0, Amsterdam, Netherlands) statistical software.

Repeat Sprint Exercise Testing

Study participants completed a standardized warm-up protocol on the cycle ergometer before the repeated sprint exercise (RSE) testing assessment. The standardized warm up is an adaptation of a standardized protocol utilized used by Mendez-Villaneuva (Billaut et al., 2006; Craig et al., 2000; Mendez-Villanueva et al., 2008). It consisted of 5 minutes at 100-120 watts, (3) 2 second maximal sprints with 30 seconds of recovery between each, followed by 3 minutes of easy pedaling at 100-120 watts, thereafter maximal sprint efforts (performed seated) began. The repeat sprint exercise test portion of this study is based on previous studies of Glaister, Bishop and Mendez-Villaneuva (Girard et al., 2011; Glaister 2005). Participants were "fitted" to the Velotron cycle ergometer (Racermate Inc., Seattle, WA) using the measurements of each participants own bicycle to ensure more familiarity and comfort of fit during the RSE testing portion. The use of cycling specific shoes and the participants' own pedal system were fitted to the testing equipment. Participants were given a 5 second countdown before each of the (15) maximal sprint efforts of 6 seconds each. With this 5 second warning before the start of each maximal trial, participants were instructed to move the pedal crank to a standardized 45° angle from the parallel crank position on either the right or left side (based on study participant selection at beginning of protocol). Study participants were instructed to pedal "as fast and as hard as possible" during each maximal effort trial, with strong verbal encouragement throughout each trial. All maximal trials were performed seated throughout each 6 second trial to remove any confounding effects of a standing position (Faria et al., 2005). The 30 second recovery periods were performed passively, where study participants sat quietly without pedaling on the bike as the load remained constant during each of the (15) trials. Resistance was based on each individuals' body mass and standardized throughout each maximal trial at 7% of body mass, based on related studies (Katch et al., 1977). Peak power, mean power, peak and mean cadence, rating of perceived exertion were all collected for each trial. Velotron cycle ergometer (Racermate Inc., Seattle, WA) supplied software was used for recording power and cadence data, exportation of data to a Comma Separated Values (CSV) file occured after each participants' completion for further analysis using Microsoft Excel- (Microsoft Corporation, Redmond, WA) and JASP (Version 0.10.0, Amsterdam, Netherlands) statistical software.

Isometric Strength Testing

Study participants completed a standardized general warm-up protocol before the first of three isometric strength testing assessments. After completing this standardized general warm-up, participants then completed a specific warm-up consisting of one set of five repetitions of the back squat with a 20-kg barbell followed by three sets of five repetitions at 40 to 60-kg, each separated by 1-minute of rest to ensure proper warm-up and decrease likelihood of incurring injury.

The isometric squat testing (IST) uses an adapted protocol from Bazyler and colleagues (Bazyler et al., 2015; McBride et al., 2006; Wagle et al., 2017). Data was collected using a dual force plate design (2 x 91 cm x 45.5 cm force plates, RoughDeck HP, Rice Lake, WI) inside a custom-built isometric rack device, with data sampled at 1,000 Hz through LabVIEW (version 2015, National Instruments). Force plates were calibrated to laboratory specifications before each of the testing sessions. Study participants' bar height was set on an individual basis to allow the subject to have a knee angle of 120° ±5°, checked with a goniometer (McBride et al., 2006; Wagle et al., 2017). Performance studies have found that cyclists produce optimum power output with a knee angle reaching approximately between 115° to 125° (Burke 2003; Peveler 2007; Pruitt 2006), this extended knee angle relates well to that of the isometric squat set-up.

Following the standardized general and specific warm-up protocols, participants completed IST trials at 50% and 75% of their perceived maximal effort. Study participants were instructed to push "as fast and as hard as possible" during each maximal effort trial. Prior to the start of each maximal trial, participants were instructed to apply constant pressure on the bar before beginning their maximal effort squat with a countdown of "3, 2, 1, Go!" to reduce likelihood of countermovement and possible negation of said trial. Strong verbal encouragement was given to the participant during each maximal trial. Each subject performed a minimum of two maximal effort trials. If a countermovement of greater than 200 N was detected or trials differed by more than 250 N, subjects were required to complete an additional trial (Kraska et al., 2009; Wagle et al., 2017). Each maximal effort trial was followed by a mandatory three-minute rest interval, where the study participant remained seated in a chair for optimal recovery from said effort.

For the following three ISTs (IST-Post, IST-Post10, IST-Post25) of the session (following the RSE protocol), the standardized general and specific warm-up was not implemented. Study participants advanced from the cycle ergometer to the 50% and 75% of perceived maximal effort trials before beginning (specifically IST-Post) each successive maximal effort trials attempt. LabVIEW (v2015 7.1, National Instruments, Austin, TX) software was used for processing kinetic data through a custom interface designed for the Center of Excellence in Sport Science and Coaches Education. Isometric peak force (IPF), rate of force development over 50, 90, 200ms (RFD50, RFD90, RFD200), impulse over 50, 90, 200ms (IMP50, IMP90, IMP200) were collected from each participant trial (Wagle et al., 2017).

CHAPTER 4

THE RELATIONSHIP BETWEEN REPEATED-SPRINT CYCLING PERFORMANCE AND MEASURES OF AEROBIC POWER AND MEASURES OF STRENGTH AND POWER VARIABLES

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ABSTRACT

The physiological demands of competitive cycling are inherently uncertain in nature, dependent on a wide range of variables and requiring repeated accelerations throughout that rely on both aerobic and anaerobic energy pathways. Purpose: The purpose of this study was to examine the relationships between repeated sprint performance, aerobic power, and strength and power indices in competitive cyclists. Methods: Ten competitive cyclists were assessed during two different testing sessions, with at least 1 week between sessions. Assessment of aerobic power was completed during the first session. During the second session participants completed a baseline isometric squat test to assess strength and power measures. After a brief recovery period participants completed a repeat sprint cycling protocol consisting of (15) 6 second sprints, after which they completed three more isometric testing bouts. Results: The results of this study indicated that there were no statistically significant correlations between VO_2max and RSE fatigue percent decrement or isometric PF percent decrement and RSE fatigue decrement between. The results did indicate that there were statistically significant relationships between VO_2max and mean RSE peak power, the isometric squat best PF and RSE best peak power, and between isometric squat best PF and RSE % fatigue decrement. Conclusions: The findings in this study not only show the importance of aerobic power, and peak power capabilities for a sport such as competitive cycling but also their resulting impact on repeat sprint ability. We can conclude that in this study, participants that exhibited superior strength and power characteristics were able to apply force efficiently on the bicycle, which may be advantageous during cycling competitions.

Development and maintenance of aerobic power is extremely important in any endurance sport endeavor and should be an essential part of the athlete's training regimen. The addition of strength and power training would greatly benefit the athlete by improving the economy of movement, delaying fatigue, improving anaerobic capacity, and overall enhancing maximal speed.

Introduction

Within the last several decades, repeat sprint ability (RSA) has been studied broadly and is considered an important athletic characteristic in many sports for success (Bishop and Spencer 2004; Buchheit 2012; Wadley & Le Rossignol 1998). The specific fitness characteristics and energetic requirements of RSA are still debated and may be for some time amongst sport researchers and coaches (Spencer et al., 2005). The application has surprisingly not received much attention as a viable component in the endurance sport athlete's realm, specifically within the sport of cycling. Previously described as one of the most challenging of all sports by combining a variety of durations, intensities, and frequencies in one event (Jeukendrup et al., 2000), competitive cycling events are inherently stochastic in nature (Allen & Coggan 2010), requiring repeated sprints throughout that rely on both aerobic and anaerobic power; which require a successful cycling athlete to possess an ability to produce repeated high power bouts of a short duration while continuing high overall power for long duration (Faria et al., 2005).

To deliver optimal performance(s), cycling speed will have to increase to a point where demand for power matches the power supply from all energy sources available (Olds et al., 1993). The necessity to cycle at a faster velocity than one's competitors in any competitive cycling event will be dependent on a multitude of complex interactions based on the athlete's physiological state (ie; an athlete's aerobic power [VO_2max], their lactate threshold [LT], economy of movement and gross mechanical efficiency on the bike), environment in which the athlete must perform (ie; environment temperature, humidity, wind velocity and direction, altitude, gradient of course, terrain type) and mechanical variables (ie; type of bicycle used, aerodynamics of machine, tire application for terrain, components, and gearing) (Jeukendrup et al., 2000).

In addition to low intensity exercise endurance (LIEE), the variety of factors (physiological, environmental, and mechanical variables aforementioned) impacting performance require moderate intensity exercise endurance (MIEE) and high intensity exercise endurance (HIEE) for success. With this understanding, anaerobic power and neuromuscular characteristics are and should be factored into long duration endurance performance, especially when athletes are matched for aerobic power (Bulbulian et al., 1986; Houmard et al. 1991; Paavolainen et al., 1999).

A hypothesis relating aerobic fitness and fatigue during multiple sprint exercise was formed due to phosphocreatine replenishment and removal of accumulated intracellular phosphate being primarily oxygen-dependent processes (Glaister 2005). But there has been confounding evidence found regarding this hypothesis. Some researchers have reported significant relationships between VO_2max and RSA (Bishop et al., 2004; Edge et al. 2006; Glaister 2005; Spencer et al., 2005), however, the findings of other studies have not agreed (Aziz et al., 2007; Bishop et al., 2003; Castagna et al., 2007). This supports findings that the ability to perform sprints repeatedly was related to anaerobic characteristics, the ability to buffer hydrogen ions as byproducts, and finally, muscle glycogen concentrations (Bishop et al. 2004; Edge et al., 2006; Gaitanos et al., 1993; Glaister 2008). With this evidence it may be assumed that repeat sprint ability has influential contributions from both aerobic and anaerobic systems for high peak power output and maintenance of ability to deliver this repeated maximal work.

To accurately measure performance drop-off during a bout of repeat sprint work, several authors have investigated the impact of calculation methods on the reliability of fatigue scores during repeated sprints. Oliver reported improved reliability when the performance reduction during a repeated sprint test was reported as a percentage decrement score, as opposed to a fatigue index (Glaister 2008; McGawley & Bishop 2006; Oliver 2009). This method is still inclusive of variability with CVs ranging between 11 and 50% (Bishop & Spencer 2004; Glaister et al., 2004; McGawley & Bishop 2006; Oliver 2009; Oliver et al., 2006). Utilizing test data, the percentage decrement can be calculated from the mean sprint time and the fastest sprint time, which have been shown to be reliable, with CVs < 2.7% (ICC) across a number of studies (Oliver et al., 2006; Spencer et al., 2006).

To better understand the unique physiological characteristics of cyclists and the unique competitive demands placed upon them, as well as a way to prioritize their training regimes the purpose of this study was to attempt to elucidate the relationship of aerobic power, strength and power indices, and repeat sprint ability indices in competitive cyclists.

Methods

Introduction

To investigate the relationship of aerobic power, strength and power measure indices, and repeat sprint ability, a two part study was carried out. The first part of this study was to evaluate aerobic power capacities of the study participants. The second part of the study included testing participants to determine isometric strength measures, specifically peak force and rate of force development, as well as participants completing the RSE protocol to determine total fatigue resistance capability throughout the sprint protocol and the impact of the fatigue on further measures of the isometric strength measures.

Participants

Ten competitive road cyclists (age: 22.3 ± 4.9 years, body height: 1.73 ± .5 meters, body mass: 68.5 ± 7.3 kilogram, body fat: 11.6 ±7.1 %) participated in this study. All participants were currently competing or preparing for their season in the discipline of road, track, and mountain cycling or sprint triathlon. Study participants were selected based on their competitive involvement with cycling and subsequent training experience. None of the participants reported any current or ongoing illness or injury. All participants read, signed and acknowledged the processes for all testing described/ detailed in the form of the East Tennessee State University approved Informed Consent Document prior to beginning any of the research testing protocols.

Procedures

All testing sessions were conducted indoors in a sport science laboratory on the grounds of East Tennessee State University. All study participants completed two testing sessions, with at least 1 week between testing sessions. During the first session participants completed their body composition assessment, a standardized cycle ergometer warm-up of 10 minutes including three 6 sec sprint familiarizations (5 minutes at 100-120 watts, (3) 6 seconds maximal sprints with 60 second recovery, 2 minutes at 100-120 watts), a maximal VO_2 test, shortly thereafter followed by isometric squat position trial/ familiarization. During the second session participants completed a standardized general warm-up and specific warm-up protocols, isometric squat testing (IST-Pre), a repeat sprint cycle ergometer test (RSE) of (15) x 6 seconds with 30 second passive recovery, isometric squat testing (IST-Post), 10 minute recovery period, isometric squat testing (IST-Post10), 15 minute recovery period, and concluded with isometric squat testing (IST-Post25). All testing sessions were completed during similar hours of the day (+/- 1hr) and participants were asked to follow normal diet concurrent with any competitive race or training day and to refrain from any form of intense physical activity 48 hours prior to their scheduled testing sessions.

Aerobic Power Testing

During the first testing session, after completing informed consent procedures and body composition procedures; participants completed an aerobic power test on an electronically-braked cycle ergometer (Velotron, Racermate Inc., Seattle, WA). The test cycle was adjusted to reflect the measurements of each participants own bicycle to ensure more familiarity and comfort of fit during the test. The use of the participants' own cycling specific shoes, pedal system and saddle were fitted to the cycle ergometer. Following those steps, participants completed a standardized warm-up protocol, consisting of 5 minutes at 100-120 watts, (3) 6 second maximal sprints with 30 seconds of recovery between each, followed by 2 minutes of easy pedaling at 100 watts on the cycle ergometer before the start of the maximal oxygen uptake (VO_2 max) testing assessment. The standardized warm up is an adaptation of a standardized protocol of Billaut and colleagues and of that recommended by Craig and colleagues (Billaut et al., 2006; Craig et al., 2000). The maximal oxygen uptake testing portion was a ramp incremental test where resistance loads were standardized based on study participant body mass with starting wattages differing for males and females as outlined in Table 1 (Balmer et al., 2000; Winter et al., 2006). Testing concluded when participant could no longer maintain a cadence of 70 revolutions per minute or voluntarily terminated the test due to fatigue, test administrators monitored participants readiness before advancing subsequent stages of test.

Table 1.

Ramp Test Reference Values

Weight (kg)	Males		Female	
	Start (w)	Ramp ($w \cdot min^{-1}$)	Start (w)	Ramp ($w \cdot min^{-1}$)
< 45			100 - 120	13
45 - 49			110 - 130	14
50 - 54	140 - 160	17	120 - 140	15
55 - 59	150 - 170	18	130 - 150	16
60 - 64	160 - 180	19	140 - 160	17
65 - 69	170 - 190	20	150 - 170	18
70 - 74	180 - 200	21	160 - 180	19
75 - 79	190 - 210	22		
80+	200 - 220	23		

Inspired and expired gases were assessed using a metabolic cart (TrueOne 2400, Parvo Medics, Sandy, UT) to determine the VO_2 per stage. Calibration measurements were performed prior to each test. After completion of the warm-up period, the participant was fitted with a head harness and corresponding mouthpiece with a one-way valve and hose to collect gases, and nostril clamp.

Repeated Sprint Test

During the second testing session, study participants completed a standardized warm-up protocol on the cycle ergometer before the repeated sprint exercise (RSE) testing assessment. The standardized warm up was an adaptation of a standardized protocol used by Mendez-Villaneuva (Billaut et al. 2006; Craig et al., 2000; Mendez-Villanueva et al., 2008). It consisted of 5 minutes at 100-120 watts, (3) 2 second maximal sprints with 30 seconds of recovery between each, followed by 3 minutes of easy pedaling at 100-120 watts, thereafter maximal sprint efforts (performed seated) began. The repeat sprint exercise test portion of this study is based on previous studies of Glaister, Bishop and Mendez-Villaneuva (Girard et al. 2011; Glaister 2005). Participants were “fitted” to the Velotron cycle ergometer (Racermate Inc., Seattle, WA) using the measurements of each participants own bicycle as well as their own cycling shoes, pedal system, and saddle as was the same condition during their first testing session for the aerobic power test protocol. Participants were given a 5 second countdown before each of the (15) maximal sprint efforts of 6 seconds each. With this 5 second warning before the start of each maximal trial, participants were instructed to move the pedal crank to a standardized 45° angle from the parallel crank position on either the right or left side (based on study participant selection at beginning of protocol). Study participants were instructed to pedal “as fast and as hard as possible” during each maximal effort trial, with strong verbal encouragement throughout each trial. All maximal trials were performed seated throughout each 6 second trial to remove any confounding effects of a standing position (Faria et al. 2005). The 30 second recovery periods were performed passively, where study participants sat quietly without pedaling on the bike as the load remained constant during each of the (15) trials. Resistance was based on each individuals’ body mass and standardized throughout each maximal trial at 7% of body mass, based on related studies (Katch et al., 1977).

Isometric Squat

Also during the second testing session, study participants completed a standardized general warm-up protocol before the first of four independent isometric strength testing assessments. After completing the standardized general warm-up, participants completed a specific warm-up consisting of one set of five repetitions of the back squat with a 20-kg barbell followed by three sets of five repetitions at 40 to 60-kg, each separated by 1-minute of rest to ensure proper warm-up and decrease likelihood of incurring injury.

The isometric squat testing (IST) uses an adapted protocol from Bazyler and colleagues (Bazyler et al., 2015; McBride et al., 2006; Wagle et al., 2017). Data was collected using a dual force plate design (2 x 91 cm x 45.5 cm force plates, RoughDeck HP, Rice Lake, WI) inside a custom-built isometric rack device, with data sampled at 1,000 Hz through LabVIEW (version 2015, National Instruments). Force plates were calibrated to laboratory specifications before each of the testing sessions.

Study participants' bar height was set on an individual basis to allow the subject to have a knee angle of 120° ±5°, checked with a goniometer (McBride et al., 2006; Wagle et al., 2017). Performance studies have found that cyclists produce optimum power output with a knee angle reaching approximately between 115° to 125° (Burke 2003; Peveler 2007; Pruitt 2006), this extended knee angle relates well to that of the isometric squat set-up. The isometric squat test was chosen for this study for the moderate to strong relationships between isometric peak force (IPF), impulse (IMP) to the 1-repetition max (RM) squat (Bazyler et al., 2015).

Following the standardized general and specific warm-up protocols, participants completed IST trials at 50% and 75% of their perceived maximal effort as warm-ups to maximal trial conditions. Study participants were instructed to push "as fast and as hard as possible" during each maximal effort trial. Prior to the start of each maximal trial, participants were instructed to apply constant pressure on the bar before beginning their maximal effort squat with a countdown of "3, 2, 1, Go!" to reduce likelihood of countermovement and possible negation of said trial. Strong verbal encouragement was supplied to the participant during each maximal trial. Each subject performed a minimum of two maximal effort trials. If a countermovement of greater than 200 N was detected or trials differed by more than 250 N, subjects were required to complete an additional trial (Kraska et al., 2009; Wagle et al., 2017). Each maximal effort trial was followed by a mandatory three-minute rest interval, where the study participant remained seated in a chair for optimal recovery from said effort.

For the following three ISTs (IST-Post, IST-Post10, IST-Post25) of the session (after the RSE protocol), the standardized general and specific warm-up was not implemented. Study participants advanced from the cycle ergometer to the 50% and 75% of perceived maximal effort trials before beginning (IST-Post__) each successive maximal effort trials attempt.

Statistical Analysis

Data analysis was performed using JASP Team (Version 0.10.0, Amsterdam, Netherlands) statistical software. Values have been expressed as mean and SD. Pearson's product-moment correlation coefficients were used to examine correlations between variables. Magnitude based scaling of the correlations were determined based on the work of Hopkins using the following: $r < 0.1$,trivial; 0.1 – 0.3, small; 0.3 – 0.5, moderate; 0.5 –0.7, large; 0.7 – 0.9, very large; 0.9, nearly perfect; and 1 perfect (Hopkins et al., 2009). Statistical significance was set at $p \leq 0.05$ (Fisher 1992).

Results

Mean ± SD of repeat sprint exercise, aerobic power, and isometric squat performance indices, are presented in Table 2. Values have been shown to include absolute, relative, and allometric scaling. The allometric scale used in this analysis allows the variable to be normalized to body mass to the power of 0.67 (variable / body mass in kilogram ^ 0.67), allowing a comparison of performance between study participants independent of their body mass (Suchomel et al., 2018). The correlations between indices of repeat sprint exercise, aerobic power, and isometric squat are shown in Table 3.

No statistically significant correlations were found between VO_2max, or the isometric squat performance and RSA performance indices. Statistically significant large correlations were found between VO_2max (L/min) and mean RSE peak power ($r = 0.744$, $p = 0.014$), VO_2max (ml/kg/min) and repeat sprint % fatigue decrement ($r = 0.700$, p =

0.024), as well as between the isometric squat best peak force and repeat sprint best peak power ($r = 0.710$, $p = 0.021$), and between isometric squat best peak force and repeat sprint % fatigue decrement ($r = -0.705$, $p = 0.0\ 21$), as shown in Figures 1-4.

Table 2.

Descriptive data of RSA performance indices, Vo2max, Isometric squat testing

	Mean	*SD*
RSE Mean PP (W)	628.14	67.22
RSE Mean PP (W·kg)	9.2	0.75
RSE Mean PPa ($W{\cdot}kg^{\wedge 0.67}$)	37.04	2.87
RSE Best PP (W)	721.60	111.24
RSE Best PP (W·kg)	10.51	0.74
RSE Best PPa ($W{\cdot}kg^{\wedge 0.67}$)	42.37	3.95
RSE % Dec	12.20	7.10
VO_2max ($L{\cdot}min^{-1}$)	4.58	5.25
VO_2max ($ml{\cdot}kg{\cdot}min^{-1}$)	67.30	9.30
ISO Best PF (N)	2789.24	553.86
ISO Best PF (N·kg)	40.50	5.25
ISO Best PFa ($N{\cdot}kg^{\wedge 0.67}$)	163.50	24.07
ISO % Dec	7.23	4.69

RSE = repeat sprint exercise, PP = peak power, ISO = isometric squat testing, PF = peak force, a = allometrically scaled, % Dec = Percent Decrement

Table 3.

Pearson Correlation Coefficients

Variable	VO_2 ($L{\cdot}min^{-1}$)	VO_2 ($ml{\cdot}kg{\cdot}min^{-1}$)	ISO Best PF (N)	ISO Best PF (N·kg)	ISO Best PFa ($N{\cdot}kg^{0.67}$)	ISO PF %Dec
RSE Mean PP	*0.744	0.173	0.451	0.150	0.293	-0.181
RSE Best PP	0.376	-0.307	*0.710	0.332	0.512	-0.255
RSE %Dec	0.167	*0.700	*-0.705	-0.404	-0.550	0.296

* statistically significant (p Value < .05)

RSE = repeat sprint exercise, PP= peak power, ISO = isometric squat testing, PF = peak force, a = allometrically scaled, %Dec = Percent Decrement

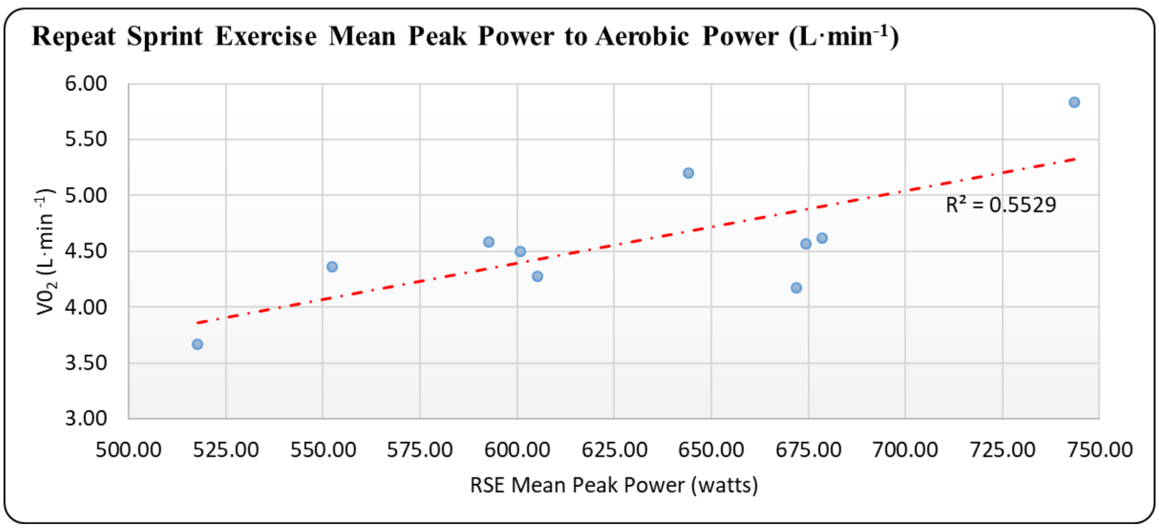

Figure 1. Repeat Sprint Exercise Mean Peak Power to Aerobic Power

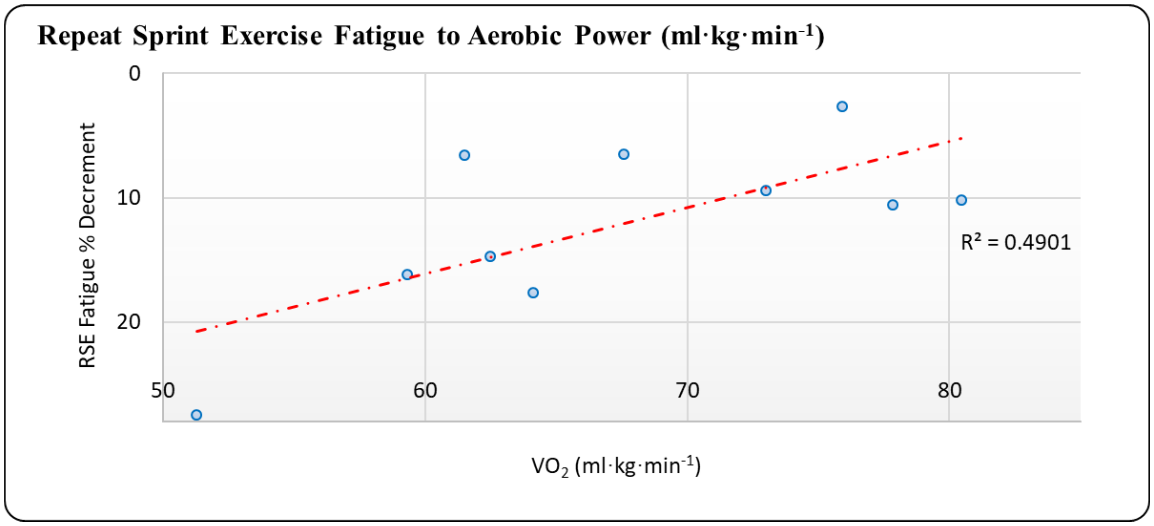

Figure 2. Repeat Sprint Exercise Fatigue to Aerobic Power

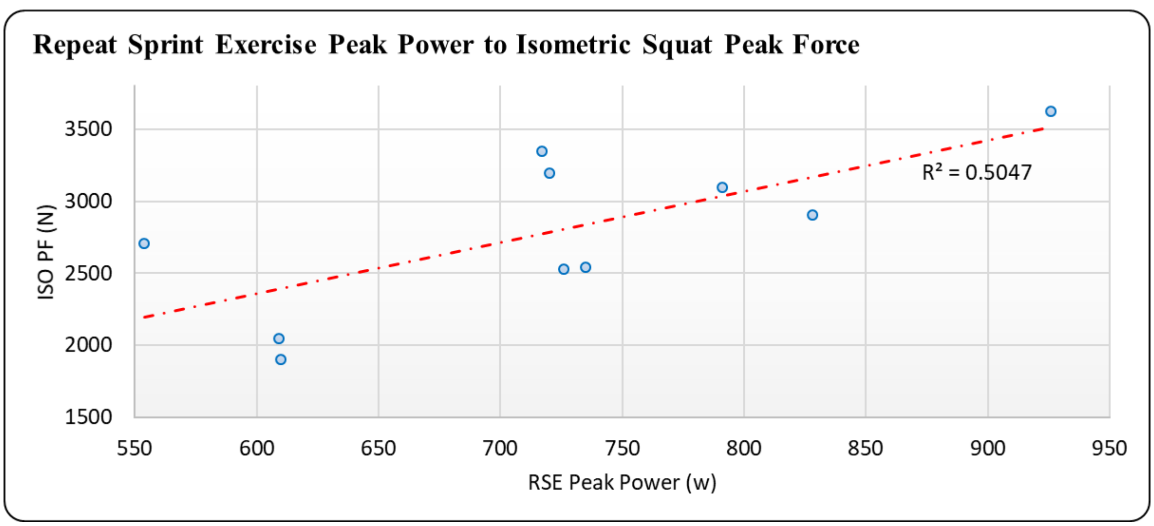

Figure 3. Repeat Sprint Exercise Peak Power to Isometric Squat Peak Force

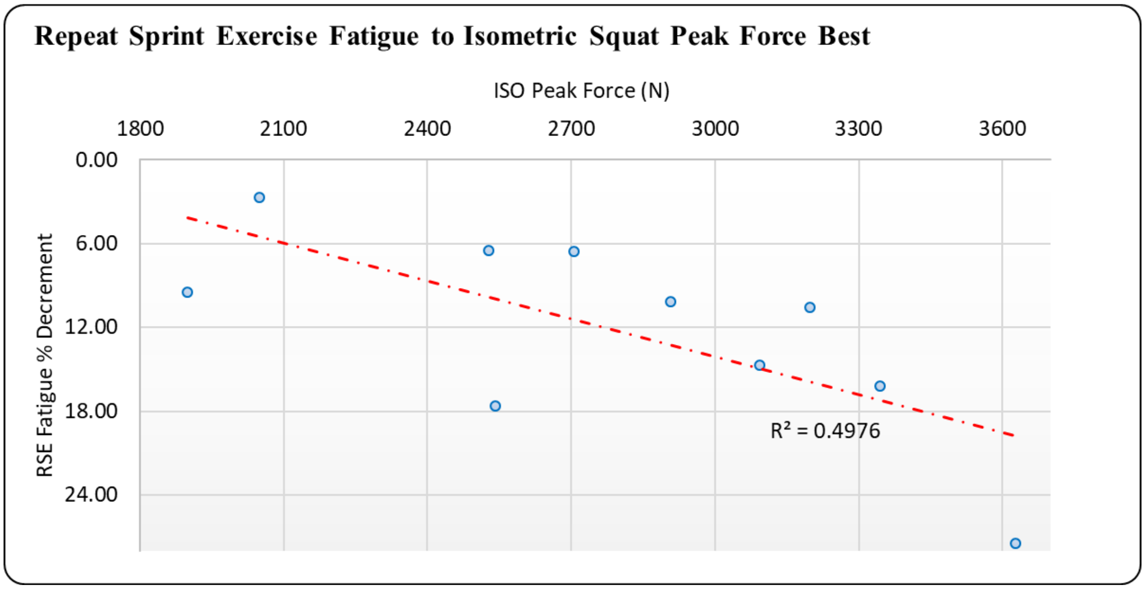

Figure 4. Repeat Sprint Exercise Fatigue to Isometric Squat Peak Force Best

Discussion

The goal of the present study was to examine the relationships between repeated sprint performance indices and aerobic power, strength and power indices in competitive cyclists.

The results of this study concluded that though there were no significant correlations between aerobic power and repeated sprint ability performance (absolute VO_2max and RSE fatigue percent decrement) ($r = 0.167$, $p = 0.637$); nor were there significant correlations between the strength and power variable and repeated sprint ability performance (ISO PF percent decrement and RSE fatigue percent decrement) ($r = 0.296$, $p = 0.400$). However, there were significant correlations between individual variables of each of these tests. The non-significant results agree with previous studies (Aziz et al., 2007; Bishop et al., 2003; Castagna et al., 2007; Dardouri et al., 2014). While there have been other studies that have reported significant correlations between VO_2max and RSA performance (Edge et al., 2006; Glaister 2005), the differences may be due to variations in sample size and protocols used to determine RSA performance.

Interestingly, our study did conclude that there was a statistically significant relationship between relative VO_2max (ml/kg/min) and repeat sprint percent fatigue decrement ($r = 0.700$, $p = 0.024$), VO_2max and the mean RSE peak power ($r = 0.744$, $p = 0.014$), as well as between the isometric squat (ISO) best peak force and repeat sprint (RSE) best peak power, and between isometric squat (ISO) best peak force and repeat sprint (RSE) % fatigue decrement, ($r = 0.710$, $p = 0.021$) ($r = -0.705$, $p = 0.021$) respectively.

The significant large correlation between VO_2max and the mean peak power of study participants for their fifteen sprints ($r = 0.744$, $p = 0.014$), may be related to their ability to maintain performance throughout an aerobic exercise bout. This is not to be confused with the study participants' ability to produce high peak power in repeated sprints, only their ability to continue doing sprints, as we saw no statistically significant correlation of VO_2max and study participants' best peak power in the RSE. This difference may be related more to the onset of blood lactate (OBLA), as Da Silva et al. reported that RSA was more strongly correlated to OBLA than VO_2max (da Silva et al., 2010; Dardouri et al. 2014). Mendez Villanueva et al. had similar findings in 2008, stated that differences were due to study participants with little anaerobic power showed higher resistance to fatigue during RSE. The study participants with high anaerobic power showed larger power decrement, less resistance to fatigue during the RSE (Mendez-Villanueva et al., 2008). Further supporting this notion are significant correlations found between peak anaerobic power during a Wingate testing procedure and RSE (Bishop et al., 2004; Bishop and Spencer 2004).

This finding relates well to other observations in the isometric squat (ISO) test where best peak force and repeat sprint (RSE) best peak power, as well as RSE % fatigue decrement show significant large correlations ($r = 0.710$, $p = 0.021$) ($r = -0.705$, $p = 0.021$), respectively. The IST protocol used in this study was chosen and designed as a means of measuring strength and explosiveness. Past research has shown that an isometric squat is strongly related to 1-repitition maximum barbell back squat (Bazyler et al., 2015; Blazevich et al., 2002; Nuzzo et al., 2008). As such, strength is defined as an ability to produce external force by contraction of a muscle or group of muscles under a specific set of conditions (Stone et al., 2004; Stone et al., 2007). Applying maximal force quicker than an opponent is where most athletes will gain an advantage. The association of force and time, referred to as power, is related to Newton's second law, where force equals mass times acceleration (Stone et al., 2016). Rate of force development (RFD) and resultant power are simply products of aforementioned strength production, whereby being measured with a time/ velocity component (Stone et al., 2016). Previous research has shown that peak RFD is an important predictor of success in various athletic pursuits, specifically sprint cycling (Bazyler et al., 2015; Stone et al., 2004; McBride et al., 2009).

With these findings of related research, it may be easier to understand the significant correlations found in this study. The isometric peak force measurement resulted in a statistically significant large correlation with the RSE best peak power, ($r = 0.710$, $p = 0.021$). In other words, the study participants that exhibited more strength and power characteristics during a test of isometric maximum strength were also able to apply force efficiently on the bicycle during the RSE testing protocol. We also observed a statistically significant large negative correlation between the isometric peak force measurement and the RSE fatigue % decrement score, ($r = -0.705$, $p = 0.021$). Related to the aforementioned correlation, the study participants that exhibited more strength and power characteristics by producing superior results in the isometric maximum strength testing protocol and producing higher power outputs during the RSE portion of the study also had higher rates of fatigue during said RSE test. This observation is also supported by other studies, the works of Mendez Villanueva and Gaitanos, who similarly noted study participants who possessed highly anaerobic power and resultant sprinting capabilities were more dependent on anaerobic metabolism during their RSE testing protocols and experienced larger power decrements than those less dependent on anaerobic means (Gaitanos et al., 1993; Mendez-Villanueva et al., 2008).

Practical Application

In conclusion, the results of this study despite showing weak correlations between total isometric maximum strength, aerobic power and RSA testing measures there have been strong correlations between separate variables of each of these tests. We can clearly conclude that in this study, the participants who exhibited superior strength and power characteristics were able to apply such dynamically on the bicycle, which may be advantageous during competitions. Maintenance and development of aerobic power is extremely important in any endurance sport endeavor and should be an essential part of the athlete's training regimen. The addition of strength and power training will greatly benefit the athlete by improving the economy of movement, delaying fatigue, improving anaerobic capacity, and overall enhancing maximal speed (Ronnestad & Mujika 2014). More research in this area of sport-specific application using trained individuals is definitely a necessity to further the field of sport physiology.

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CHAPTER 5

THE EFFECTS OF AN ACUTE BOUT OF REPEATED SPRINT CYCLE ERGOMETRY ON FORCE PRODUCTION CAPABILITIES VIA ISOMETRIC EXERCISE

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ABSTRACT

Success in competitive cycling is dependent on numerous factors that include both aerobic power and measures of explosive strength. It is not uncommon for a competitive cyclist to have to perform in multiple races or “heats” during a single day of competition. For this reason, measures of strength and power were assessed isometrically to determine rate of force development and peak force, among other variables in a fresh as well as fatigued state. Purpose: The purpose of this study was to examine the effects of fatigue induced from a RSE protocol, which may be characteristic of the performance demands experienced by cyclists in competition, on measures of strength and power indices. A hypothesis of the study was that participants would experience similar fatigue decrements seen in the RSE protocol as during the isometric squat testing protocols, as seen in measures of peak force and RFD. Methods: Ten competitive cyclists were assessed during two different testing sessions, with at least 1 week between sessions. During the second session participants completed a baseline isometric squat test to assess strength and power measures. After a brief recovery period participants completed a fatigue inducing repeat sprint cycling protocol consisting of (15) 6 second sprints, after which they completed three more isometric testing bouts. Results: Results of a 1 x 4 repeated measures analysis of variance showed no significant time effects on peak force, rate of force development, or impulse. Additional effect size estimates were carried out to determine specific effects on trials. Fatigue did show to have a medium effect on rate of force development. Conclusions: The RSE protocol utilized for this study induced, on average, what is considered moderate fatigue to participants. The effect of fatigue on measures of strength and power variables were “medium” at best. These findings support

similar research results but may serve as the start to further research in assessing explosive strength measures in relation to RSA inquires.

Introduction

Based on recent research findings, the relationship between power and fatigue decrement is that the greater, or more forceful, an initial effort produced by a muscle or motor unit during a specific task there will be less fatigue resistance, or increased fatigue decrement, experienced in that particular muscle or motor unit (Enoka & Duchateau 2008; Mendez-Villanueva et al., 2008). Gaitanos and Mendez Villanueva have both concluded that their respective study participants who had great anaerobic power and sprinting capabilities experienced larger power decrements than other study participants with less power and subsequent sprinting capabilities (Gaitanos et al., 1993; Mendez-Villanueva et al., 2008).

When investigating strength, it can be defined as the ability to produce external force by contraction of a muscle or group of muscles under a specific set of conditions (Stone et al., 2004; Stone et al., 2007). Power (P) incorporates strength and is the rate of doing work (P = force x velocity) (Stone et al., 2004). Therefore, we may argue that strength is a necessary component in power development, as the ability to generate force or accelerate an object (Stone et al., 2004). Arriving at this conclusion, it is clear to see the importance of rate of force development (RFD) in competitive sports.

We have concluded that individuals who possess greater peak power outputs and subsequent sprint abilities usually experience the greatest fatigue decrement (Bishop 2012; Bishop and Spencer 2004; Mendez-Villanueva et al., 2008). However, the cause of performance decrements underlying the difference between peak power and subsequent trials is currently, for the most part, unknown. Fatigue has been defined as a reversible decrease in maximal power output, despite the ability to continue the specified task (Bishop 2012). This exercise-induced fatigue may be caused by a variety of reasons that range from first sprint power exhibited, nature of the task, and neural to peripheral factors (Bishop 2012).

The importance of the first, or initial, sprint performance has been correlated to power output in subsequent sprints (Bishop 2012; Bishop et al., 2003; Mendez-Villanueva et al., 2008). This may be due to an increased dependence on anaerobic metabolism to supply the muscular function needed for a maximal contraction initially; producing larger disruptions in muscle metabolites, pointing towards the force-dependent metabolic pathways that support force production regardless of force or power output produced in subsequent trials (Gaitanos et al., 1993; Mendez-Villanueva et al., 2008). The specific task being performed by an individual and their respective experience with said task may also have a role in fatigue experienced, as do the intensity, duration and type of contraction (Bishop 2012). Recent studies have reported that trial distribution, trial length, recovery period, recovery type- active or passive, type of resistance, and modality of delivery all have an impact on the fatigue decrement (Bishop 2012; Girard et al., 2011; Signorile et al. 1993).

The discussion of neural factors commonly leads to examination of surface electromyography (EMG) and whether the ability to fully contract working muscles is still present. Several studies have reported decreases in mechanical scores as well as amplitude of EMG signals, this has been evident at fatigue levels greater than 10% (Billaut & Bishop 2009; Girard et al., 2011Mendez-Villanueva et al., 2007; Mendez-Villanueva et al., 2008; Racinais et al. 2007). The use of EMG was not implemented for the current study and is therefore beyond the scope of this paper.

Peripheral factors that relate to overall fatigability of an individual have associations with muscle excitability, energy supply, and accumulation of metabolites (Bishop 2012; Girard et al., 2011). Specifically discussing muscle excitability, with mechanical work at the skeletal muscle level, ionic alterations give way to decreases in sodium (Na^+)/ potassium (K^+)- adenosine triphosphate (ATP) activity (Brooks et al., 2005). Under intense working conditions, the Na^+/ K^+ pump, which regulates muscular contraction and relaxation, cannot steadily balance the K^+ efflux out of the cells, thereby inducing an excess of muscle extra-cellular K^+ concentration (Girard et al., 2011; Juel et al., 2000). This extra-cellular K^+ ultimately impairs membrane excitability and depresses force development, by slowing inactivation of Na^+ channels and thereby reducing action potential amplitude which leads to a slowing of impulse conduction (Fuglevand et al., 1993; Girard et al., 2011; Ruff et al., 1988).

The most immediate energy supply for anaerobic pathways is produced via intramuscular phosphocreatine (PCr). Total stores in the human body are approximately 80 mmol·kg dm^{-1}, with maximal rates of breakdown that can reach 9 mmol·kg dm^{-1} (Bishop 2012; Girard et al., 2011). With particular interest in the case of RSE, stored PCr after a 6 second maximal sprint can be diminished to 35-55% of resting values with complete recovery sometimes requiring in excess of 5 minutes (Gaitanos et al., 1993; Girard et al., 2011; Tomlin & Wenger 2001). With the replenishment and complete resynthesis, it is likely that ATP/ PCr stores will only be somewhat restored before the next interval of an RSE test protocol. This inadequate replenishment of ATP/ PCr may severely limit subsequent maximal power output by an individual during repeated trials. The work of Girard, Mendez Villanueva, and Bishop suggests that more careful distribution of power output may attribute to superior PCr resynthesis during recovery periods (Girard et al., 2011).

The next most immediate energy pathway is that of anaerobic glycolysis. Anaerobic glycolysis can be responsible for as much as 40% of total energy during a 6 second maximal sprint bout with diminishing contribution during an RSE protocol, which can be as high as an 8-fold decrease over 10 trials (Gaitanos et al., 1993; Girard et al., 2011). What remains unclear with regards to anaerobic glycolysis is that if improving the maximal rates of glycolytic contributions would lead to superior performances in a RSE endeavor. An enhancement of glycolytic ATP contribution could enhance power output during the first, initial sprint which may impact fatigue resistance and may enhance average power output through subsequent trials (Girard et al., 2011).

Finally, oxidative metabolism during any RSE protocol, though quite a small contributor initially (less than 10%), can increase contribution to as much as 40% of total energy supply during the last sprints of an RSE testing protocol (Bishop 2012; Girard et al., 2011). Therefore it is not surprising that RSE performance may be enhanced by

VO_2max, by the ability to increase fatigue resistance, especially in the latter trials of the RSE testing protocol. Studies have reported significant correlations between VO_2max and fatigue decrements, presenting better fatigue resistance in those individuals with larger aerobic power capabilities (Edge et al., 2006; Glaister 2005). To confound this issue, other researchers have reported non-significant correlations between these performance measures (Aziz et al., 2007; Castagna et al., 2007; Dardouri et al., 2014). But the differences may be due to variations in sample size and protocols used to determine RSA performance.

The accumulation of metabolites (hydrogen ions) in muscle and blood during fatigue inducing exercise, such as the RSE protocol, can be supported by research findings and may be associated with adverse effects on performance (Bishop et al., 2003; Bishop & Edge 2006; Spencer et al., 2008). These accumulated metabolites may have a direct effect on ATP delivery by changing blood pH, but this has been greatly disputed in the literature (Girard et al., 2011).

The purpose of this study was to examine the effects of fatigue induced from an RSE protocol, which may be characteristic of the performance demands experienced by cyclists in competition, on strength characteristics. A hypothesis of the study is that participants would experience similar fatigue decrements seen in the RSE protocol as during the isometric squat testing protocols, as seen in measures of peak force and RFD.

Methods

Introduction

To investigate the relationship of fatigue from a repeated sprint cycle exercise on strength and power measure indices, a two part study was carried out. The first part of the study was to evaluate aerobic power capacities of the study participants. The second part of the study included testing participants to determine isometric strength measures, specifically peak force and rate of force development, as well as participants completing a RSE protocol to determine total fatigue resistance capability throughout the sprint protocol and the impact of the fatigue on further measures of the isometric strength measures.

Participants

Ten competitive cyclists (age: 22.3 ± 4.9 years, body height: 1.73 ± .5 meters, body mass: 68.5 ± 7.3 kilogram, body fat: 11.6 ± 7.1 %) participated in this study. All participants were currently competing or preparing for their season of competitive road cycling. Study participants were selected based on their competitive involvement with cycling and subsequent training experience. None of the participants reported any current or ongoing illness or injury. All participants read, signed and acknowledged the processes for all testing described and detailed in the form of the East Tennessee State University Institutional Review Board approved Informed Consent Document prior to beginning any of the research testing protocols.

Procedure

All testing sessions were conducted indoors in a sport science laboratory on the grounds of East Tennessee State University. All study participants completed two testing sessions as part of this research, with at least 1 week between testing sessions. During the first session participants completed measures associated with aerobic variables not discussed in the context of this paper, as well as familiarizations trials of the isometric squat testing protocol. During the second session participants completed a standardized general warm-up and specific warm-up protocols, isometric squat testing (IST-Pre), a repeat sprint cycle ergometer test (RSE) of (15) x 6 seconds with 30 second passive recovery, isometric squat testing (IST-Post), 10 minute recovery period, isometric squat testing (IST-Post10), 15 minute recovery period, and concluded with isometric squat testing (IST-Post25). All testing sessions were completed during similar hours of the day (±1hr) and participants were asked to follow their normal diet concurrent with any competitive race or training day and to refrain from any form of intense physical activity 48 hours prior to their scheduled testing sessions.

Repeated Sprint Test

To induce fatigue in a manner similar to that which study participants may encounter during a competitive cycling race, a repeated sprint cycling exercise protocol was used during the second testing session. Study participants completed a standardized warm-up protocol on the cycle ergometer before the repeated sprint exercise (RSE) testing assessment. The standardized warm up was an adaptation of a standardized protocol used by Mendez-Villaneuva, consisting of 5 minutes at 100-120 watts, (3) 2 second maximal sprints with 30 seconds of recovery between each, followed by 3 minutes of easy pedaling at 100-120 watts, thereafter maximal sprint efforts (performed seated) began (Billaut et al., 2006; Craig et al., 2000; Mendez-Villanueva et al., 2008). The repeat sprint exercise test portion of this study is based on previous studies of Glaister, Bishop and Mendez-Villaneuva, consisting of (15) six second maximal seated sprints with 30 seconds of recovery between each effort (Girard et al., 2011; Glaister 2005). Participants were "fitted" to the Velotron cycle ergometer (Racermate Inc., Seattle, WA) using the measurements of each participants own bicycle as well as their own cycling shoes, pedal system, and saddle as was the same condition during their first testing session for the aerobic power test protocol. Participants were given a 5 second countdown before each of the (15) maximal sprint efforts of 6 seconds each. With this 5 second warning before the start of each maximal trial, participants were instructed to move the pedal crank to a standardized 45° angle from the parallel crank position on either the right or left side (based on study participant selection at beginning of protocol). Study participants were instructed to pedal "as fast and as hard as possible" during each maximal effort trial, with strong verbal encouragement throughout each trial for maximal arousal state during each effort. All maximal trials were performed seated throughout each 6 second trial to remove any confounding effects of a standing position (Faria et al., 2005). The 30 second recovery periods were performed passively, where study participants sat quietly without pedaling on the bike as the load remained constant during each of the (15) trials. Resistance was based on each individuals' body mass and standardized throughout each maximal trial at 7% of body mass, based on related studies (Katch et al., 1977).

Isometric Squat

During this same testing session, study participants completed a standardized general warm-up protocol before the first of four independent isometric strength testing assessments. After completing the standardized general warm-up, participants completed a specific warm-up consisting of one set of five repetitions of the back squat exercise with a 20-kg barbell followed by three sets of five repetitions at 40 to 60-kg, each separated by 1-minute of rest to ensure proper warm-up and decrease likelihood of incurring injury.

The isometric squat testing (IST) uses an adapted protocol from Bazyler and colleagues (Bazyler et al., 2015; McBride et al., 2006; Wagle et al., 2017). Data was collected using a dual force plate design (2 x 91 cm x 45.5 cm force plates, RoughDeck HP, Rice Lake, WI) inside a custom-built isometric rack device, with data sampled at 1,000 Hz through LabVIEW (version 2015, National Instruments). Force plates were calibrated to laboratory specifications before each of the testing sessions. Performance studies have found that cyclists produce optimum power output with a knee angle reaching approximately between 115° to 125° (Burke 2003; Peveler 2007; Pruitt 2006), this extended knee angle relates well to that of the isometric squat set-up. Study participants' bar height was set on an individual basis to allow the subject to have a knee angle of 120° ±5°, checked with a goniometer (McBride et al., 2006; Wagle et al., 2017).

The isometric squat test was chosen for this study for the moderate to strong relationships between isometric peak force (IPF), impulse (IMP) to the 1-repetition max (RM) squat (Bazyler et al., 2015). In this regard, study participants were more easily controlled in terms of safety and recording measures. The fatigue induced during the RSE protocol prior to the post ISTs may have had detrimental effects to the safety of participants that would have been attempting maximal efforts with a barbell during an exhausted state.

Following the standardized general and specific warm-up protocols, participants completed IST trials at 50% and 75% of their perceived maximal effort as warm-ups to maximal trial conditions. Study participants were instructed to push "as fast and as hard as possible" during each maximal effort trial. Prior to the start of each maximal trial, participants were instructed to apply constant pressure on the bar before beginning their maximal effort squat with a countdown of "3, 2, 1, Go!" to reduce likelihood of countermovement and possible negation of said trial. Strong verbal encouragement was supplied to the participant during each maximal trial for increased arousal state. Each subject performed a minimum of two maximal effort trials. If a countermovement of greater than 200 N was detected or trials differed by more than 250 N, subjects were required to complete an additional trial (Kraska et al., 2009; Wagle et al., 2017). Each maximal effort trial was followed by a mandatory three-minute rest interval, where the study participant remained seated in a chair for optimal recovery from said effort.

For the following three ISTs (IST-Post, IST-Post10, IST-Post25) of the session (after the RSE protocol), the standardized general and specific warm-up was not implemented. Study participants advanced from the cycle ergometer to the 50% and 75% of perceived maximal effort trials before beginning (IST-Post__) each successive maximal effort trials attempt.

Isometric rate of force development was collected from 0 to 200ms. This is the approximate time consistent with the concentric application of pedal force during repeated cycling sprints (Martin et al. 2007).

Statistical Analysis

Data analysis was performed using JASP Team (Version 0.10.0, Amsterdam, Netherlands) statistical software. Data descriptive values expressed as mean and SD. Pearson's product-moment correlation coefficients were used to examine correlations between variables. Magnitude based scaling of the correlations was determined based on the work of Hopkins that utilized the following: $r < 0.1$,trivial; 0.1 – 0.3, small; 0.3 – 0.5, moderate; 0.5 –0.7, large; 0.7 – 0.9, very large; 0.9, nearly perfect; and 1 perfect (Hopkins, Marshall et al. 2009). Statistical significance was set at $p \leq 0.05$ (Fisher 1992).

A 1 x 4 repeated measures analysis of variance (ANOVA) was used to examine the possible effects of RSE induced fatigue on measures of strength and power performance indices. Mauchly's Test of Sphericity was checked and accounted for in results, utilizing a Greenhouse-Geisser adjustment factor for repeated measures ANOVA, if assumption of sphericity was violated ($p < 0.05$) based on epsilon value. Cohen’s *d* post hoc comparisons were run to evaluate effect (Cohen 2013) over the four test instances and scaled according to the work of Cano-Corres et al. who developed a more practical classification of the work of Hopkins (Hopkins 2002) which classifies effects as follows: r < 0,10 → very small difference, r = [0,10-0,29] → small difference, r = [0,30 – 0,49] → medium difference, r > 0,50 → big difference (Cano-Corres, Sánchez-Álvarez et al. 2012).

Results

In this study, competitive cyclists ($n = 10$) completed an RSE testing protocol as a means to induce fatigue in a manner characteristic of a cycling competition. RSE peak power (PP) and fatigue decrement (fatigue % decrement) scores reported as *Mean,* ± *SD* shown in Table 1. Isometric strength and rate of force development values shown as *Mean*, ± *SD* shown in Table 2.

Table 1.

Mean PP RSE & % Fatigue Decrement

	Peak Power (W)					
	Sprint 1	Sprint 2	Sprint 3	Sprint 4	Sprint 5	Sprint 6
Mean	716.20	706.60	685.90	666.20	652.00	630.70
SD	109.30	99.03	90.25	80.18	74.24	71.26
95% CI	638-794	635-776	620-749	608-723	599-705	579-680
	Sprint 7	Sprint 8	Sprint 9	Sprint 10	Sprint 11	Sprint 12
Mean	619.90	610.90	603.80	589.90	591.20	582.40
SD	69.17	71.95	65.47	64.25	66.72	73.71
95% CI	569-668	558-661	556-650	543-634	543-638	529-634
	Sprint 13	Sprint 14	Sprint 15	Fatigue % Decrement		
Mean	586.10	585.00	595.30	12.2		
SD	57.51	61.78	62.02	7.1		
95% CI	545-626	541-628	550-639			

Table 2.

Isometric Squat Test Values

	ISO PF (N)			
	IST	IST-Post	IST-Post10	IST-Post25
Mean	2689	2565	2500	2553
SD	535	519	458	500
95% CI	2358- 3021	2243-2887	2216-2784	2243-2863
	ISO PF (N·kg)			
	IST	IST-Post	IST-Post10	IST-Post25
Mean	39	37	36	37
SD	5	5	5	5
95% CI	36-42	34-40	33-39	34-40
	ISO PFa (N·kg$^{\wedge 0.67}$)			
	IST	IST-Post	IST-Post10	IST-Post25
Mean	158	151	147	150
SD	23	24	22	22
95% CI	144-172	136-166	133-161	136-163
	ISO RFD (N·s)			
	IST	IST-Post	IST-Post10	IST-Post25
Mean	853	471	446	428
SD	796	105	117	145
95% CI	360-1346	405-536	373-519	338-518
	ISO IMP (N·s)			
	IST	IST-Post	IST-Post10	IST-Post25
Mean	6679	7801	7323	8277
SD	3051	2361	1817	2468
95% CI	4790-8570	6340-9260	6190-8450	6750-9810

Results of the 1 x 4 repeated measures ANOVA showed no significant effect of fatigue on peak force (IPF) or rate of force development (RFD) during the isometric squat testing protocol over three time periods after the RSE. Results of the 1 x 4 repeated measures ANOVA for IPF resulted in no statistically significant values, [F (3, 27) = 1.744, p = 0.182], where an F value of 2.960 was needed for statistical significance. Results of the 1 x 4 repeated measures ANOVA for IMP resulted in no statistically significant values, [F (3, 27) = 1.164, p = 0.342], where an F value of 2.960 was needed for statistical significance. The results of the 1 x 4 repeated measures ANOVA for RFD resulted in a violation of the assumption of sphericity at $p < 0.05$ according to Mauchly's test of sphericity. To overcome this, a Greenhouse- Geisser adjustment factor was applied. Results from this analysis rendered statistically nonsignificant values [F (1.082, 9.741) = 2.585, p = 0.142], where an F value of 5.12 was needed for statistical significance.

Following this observation, additional post-hoc comparisons were run to assess any specific effect between trials for IPF RFD, and IMP measures over the four test instances using Cohen's d effect size analysis. Results of this analysis are shown in Table 3.

Table 3.

Cohen's d Post Hoc Effect Comparisons

	IST-Post		IST-Post10		IST-Post25	
	Cohen's d	*95% CI*	*Cohen's d*	*95% CI*	*Cohen's d*	*95% CI*
IST- IPF	0.24	-0.71-1.18	0.38	-0.57-1.33	0.26	-0.68-1.2
IST- RFD	0.67	-0.29-1.64	0.72	-0.25-1.69	0.74	-0.23-1.71
IST- IMP	0.41	-1.42-0.36	0.26	-1.28-0.49	0.58	-1.59-0.22

* denotes statistical significance

Correlations between repeat sprint exercise and isometric squat performance indices previously discussed are shown in Table 4. No statistically significant correlations were found but a moderate positive relationship is noted between the RFD fatigue % decrement score of the RSE and ISO test protocols.

Table 4.

Pearson Correlation Coefficients

Variable	RSE % Dec
ISO RFD % Dec	0.549
ISO PF (N) % Dec	0.296
ISO PF (N·kg) % Dec	0.296
ISO PFa (N·kg$^{\wedge 0.67}$) % Dec	0.296
ISO IMP % Dec	0.297

*statistically significant (p Value < .05)

RSE = repeat sprint exercise, ISO = isometric squat,RFD = rate of force development, PF = peak force, a = allometric scaled, IMP = impulse, % Dec = Fatigue Percent Decrement

Reliabilities for aerobic power, using a similar method, in our laboratory have consistently been ICC = 0.97. Reliabilities for peak power during the RSE protocol was ICC = 0.99. Reliabilities for isometric peak force was ICC $\leq$ 0.93. Reliabilities for isometric rate of force development (0 to 200ms) and impulse were ICC $\leq$ 0.90, 0.97 respectively.

Discussion

The results of this study concluded that there was no statistically significant effect of fatigue on PF or RFD over three different post-RSE tests. These finding relate to similar studies that have investigated the effects of RSE induced fatigue with confounding results, which may be due to discrepancies in study sample sizes and testing protocols utilized (Aziz et al., 2007; Bishop et al., 2003; Glaister et al., 2006; Wadley & Le Rossignol 1998). An attempt to further elucidate the findings, effect on specific IST trials was analyzed and shows that there was a medium effect of the RSE fatigue inducing protocol on RFD from the first to second, first to third, and first to fourth trials. This effect, though not statistically significant, is evidence of an overall decrease in performance. In that, our study participants were able to produce similar peak force outputs as before the fatigue-inducing RSE protocol, but there was a slight delay in their ability to generate these peak forces in successive trials ($r = 0.33$, $r = 0.35$, $r = 0.36$, respectively), hence our decreased RFD values. In recent research, it is widely evidenced that the ability to produce instantaneous high peak force outputs is related to success in sport (Stone et al., 2002; Suchomel et al., 2016).

We may attribute this reduction in the ability to generate power explosively to one of the aforementioned factors effecting fatigue- central and peripheral determinants (Bishop 2012; Girard et al., 2011). As central fatigue is commonly evidenced by the use of muscle surface electromyogram (EMG), we cannot make assumptions on the impact in this study due to the limitation of not utilizing this technology. However, the peripheral factors may have varying degrees of impact in this study and subsequent varying degrees for each of the ten study participants based on their own unique physiology.

An argument for peripheral fatigue must be promoted. Muscle excitability decreases ultimately impairs muscle membrane excitability and depresses force development, by slowing inactivation of Na^{+} channels and thereby reducing action potential amplitude which leads to a slowing of impulse conduction (Fuglevand et al., 1993; Girard et al., 2011; Ruff et al., 1988). We can also support the notion of energy supply limitations leading to performance reductions. None of the study participants were given nutritional supplementation during or between the testing protocols, with the exception of water for rehydration. With total PCr stores in the human body at approximately 80 mmol·kg dm^{-1}, and maximal rates of breakdown that can reach 9 mmol·kg dm^{-1} (Bishop 2012; Girard et al., 2011), and evidence that stored PCr after a 6 second maximal sprint can be diminished to 35-55% of resting values with complete recovery sometimes requiring in excess of 5 minutes (Gaitanos et al., 1993; Girard et al., 2011; Tomlin & Wenger 2001). It was very likely that replenishment and complete resynthesis of ATP/ PCr stores were only slightly restored before the next interval of the RSE test protocol. Anaerobic glycolysis, responsible for up to 40% of total energy supply during a 6 second maximal sprint bout, can diminish as much as 8-fold decrease over 10 trials of a 6 second RSE protocol (Gaitanos et al., 1993; Girard et al., 2011). Our RSE testing protocol included (15) trials, therefore necessitating increased reliance on oxidative metabolism. The contribution of which can increase to 40% of total energy contribution in the last trials of a 10 trial RSE protocol (Bishop 2012; Girard et al., 2011). Finally, a greatly contested topic in recent literature is that of metabolite accumulation. Excess hydrogen ions in muscle and blood may have an effect on pH levels thereby altering target tissue ATP/ PCr delivery and associated subsequent maximal effort trials (Bishop et al., 2003; Bishop & Edge 2006; Spencer et al., 2008).

Fatigue decrement scores < 10% are considered mild (Bishop 2012), our participants had a mean fatigue % decrement of 12.2% for RSE, 26.8% for ISO RFD, 18.7% for ISO IMP, and 7.23% for ISO PF (N), ISO PF (N·kg), ISO PFa (N·$kg^{\wedge 0.67}$), corresponding correlations shown in Table 4. It is evident that performance decrements have occurred over the specific trials in this study and the resulting performance changes are largest with regards to peak RFD during our IST protocol. We may assume that the results are a combination of the aforementioned factors but further study is certainly warranted. In previous research, findings indicated that peripheral adaptations in working muscles played a more vital role for enhanced submaximal cycling capacity than central adaptations. Clearly, relatively brief but intense sprint training can enhance both glycolytic and oxidative enzyme activity, maximal short-term power output and resultant VO_2max (Faria et al., 2005).

The results may also be indicative of the need for both aerobic and anaerobic strength training in the endurance sport populations- specifically cycling in this case; further enabling a cycling athlete to produce instantaneous high peak power efforts during necessary times in a race but also to continue to possess the ability to recover from such bouts and actively maintain a high average power output throughout remaining segments of the race. This can be supported by research that has shown strength training may enhance cycling economy (Ronnestad et al., 2010, Ronnestad & Mujika 2014; Ronnestad et al., 2015).

Practical Application

Possible causes of fatigue will vary with unique individuals, as their own physiology and how they respond to performance variables on any specific day will vary.

What was attempted in this study was to show the relationship between fatigue and the effects it may have on measures of strength and power in competitive cyclists.

Performance advantages in competitive cycling may come from altering training regimens of exclusively aerobic means to include periodized strength and power training to properly develop explosive strength capabilities. Doing so may greatly benefit the athlete by increasing peak power output, the economy of movement, delaying fatigue, improving anaerobic capacity, and overall enhancing maximal speed (Ronnestad & Mujika 2014). More research in this area of sport-specific application using trained individuals is definitely a necessity to further the field of sport physiology.

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CHAPTER 6

SUMMARY AND FUTURE DIRECTIVES

The summary of findings of this study, as a whole, were that no significant relationships existed between the main variables examined. However, further analysis of the subsequent variable performance indices rendered some interesting results that may allow us to refine the study of repeat sprint ability (RSA) in the endurance sport realm, specifically competitive cycling. The type of training required for success in the competitive cycling arena may be as unique as the athletes that take-part in it. General conclusions can be made that the characteristics of successful cyclists, in varying disciplines; genetic advantages aside, include high indices of aerobic power, high onset of blood lactate, low percent body fat, and excellent movement economy (Ronnestad et al., 2014; Vikmoen et al., 2016). We have also found and what is evidenced by recent research is the ability to produce instantaneous high peak force outputs, termed “explosive strength” is related to success in sport (Stone et al., 2002; Suchomel et al., 2016). The addition of superior strength and subsequent power capabilities, rendered through a properly periodized strength & conditioning program, integrated into a competitive cyclists training may allow newfound success in their athletic endeavors.

More research in this area of sport-specific application using trained individuals is unquestionably a necessity to further the field of sport physiology and advance performance in competitive cycling. To provide directives for future research, I would advise for increased data collection lead time- this may allow the procurement of a larger sample size. The relatively short time that the study participants were available for in the present study was quite brief regarding personal schedules, school and work conflicts and prior engagements. Cyclists, like many athletes, are committed individuals to their respective sport pursuits and attempting to lure them from their habitual training regimens can prove to be quite difficult. I would also urge future researchers to include more familiarization sessions with study participants who may not have been as familiar with strength training test measures.

The addition of supplementary testing measures such as blood draws to determine specific biomarkers throughout the RSE and aerobic power testing protocols may have proven to be useful in determining fatigue level experienced throughout. Other testing modalities such as muscle oxygen may also be beneficial to address this means.

Finally, the use of an anaerobic power reserve (APR) test, as has been used by other researchers more greatly experienced in RSE (Mendez-Villanueva et al., 2008), would have been beneficial to determine the study participants' dynamic power on the bike versus having been assessed via isometric measures only, in order to gain strength and power performance measures.

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